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CHANGES IN SEASONAL SNOWFALL IN CITIES

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THE NEED for a discussion of changes in seasonal snowfall in cities was brought to the writer's attention early in the winter of 1959, when one of the Toronto newspapers used the headline "It can't happen again." This quotation was made in direct reference to the twenty-four–hour 20.5-inch snowfall which occurred in Toronto in December, 1944. Nevertheless, it raised the question of whether or not the growth of metropolitan Toronto in itself had really changed the city's snowfall enough to justify the headline.

It is true that large cities change the climate of their location in many ways. Such changes have been fairly adequately discussed by many authors. H. Landsberg, for example, has summarized these effects and one of his conclusions is that the building of a city generally causes a rise of 1° to 2° F. in the mean temperature.[1] This agrees with conclusions reached by M. K. Thomas on the change in winter temperature which occurred with the growth of metropolitan Toronto.[2] Besides the change in temperature, there is also a probable increase in the precipitation. According to R. Geiger, this is caused by both the upward movement of air over the city and the more numerous condensation nuclei owing to atmospheric pollution.[3]

The only published reference to the effect of a city on snowfall is the following statement by Manley based on observations in England. "It is possible that the warmth of a built-up area in winter plays some part in diminishing the frequency with which falling snowflakes will be observed in inner London. This effect, in the writer's opinion, must be small."[4] This statement does not completely agree with the newspaper heading mentioned above. However, in view of the fact that the Meteorological Service of Canada has been measuring snowfall since 1843, sufficient data should have been gathered to throw some light on this apparent disagreement.

Before examining these data, there are some features that control the amount of snowfall and should be mentioned. Changes in snowfall through the growth of a city may be brought about in two ways. Any increase in the precipitation resulting from the growth of the built-up area of a city will tend to increase the snowfall. But, an increase in the temperature brought about this way will cause some of the precipitation, which would have fallen as snow if the built-up area were much smaller, to melt and reach the ground as rain. Thus these two controls tend to cancel each other out, and the question becomes which is the more efficient.

Under ideal conditions one could determine the effect of the city on snowfall simply by taking simultaneous observations at comparable sites both within and outside the city. Unfortunately the metropolitan areas have grown in regions where such comparable sites, where all orographic influences other than the city itself are equal, are non-existent. This leaves the alternative of studying the long-term record for a single site around which a large city has grown since the record first began, and from this trying to determine if the snowfall has changed throughout the period. When this method is used, the comparability of the data resulting from measurements of snowfall over a long period must be considered. Whether there are trends in the temperature and precipitation, other than those due to the growing city, must also be taken into account.

The method of measuring snowfall in Canada has not been significantly altered since 1843. The observer is still instructed to measure the depth of the freshly fallen snow in several representative spots with a ruler, and report the average depth. There have, however, been some changes, such as the frequency of the measurements. These were generally taken at 8-hour intervals until 1932, at 12-hour intervals from

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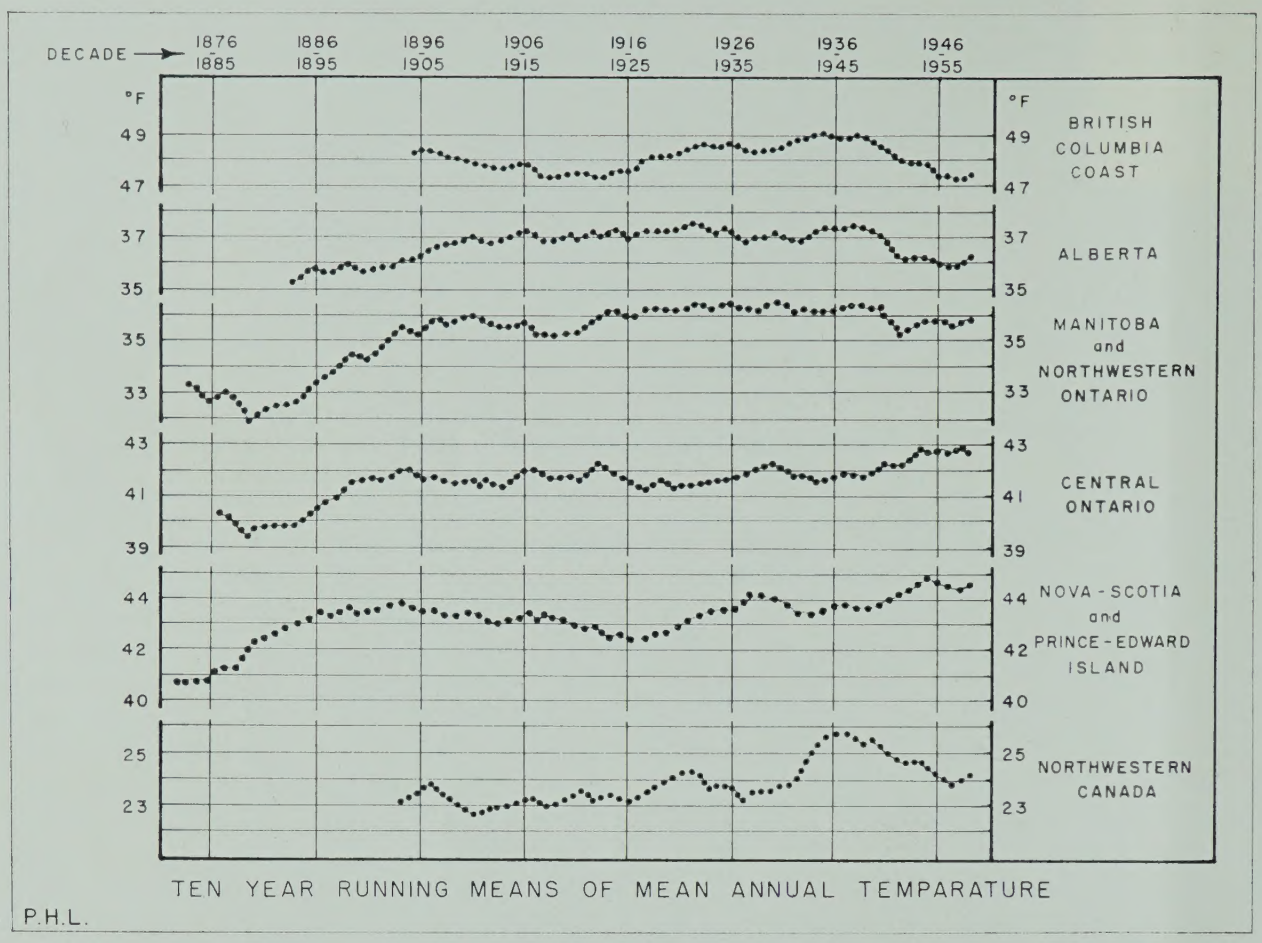

FIG. 1.

1932 to 1940, and at 6-hour intervals from 1941 until the present. As the structure of a snowflake begins to break down because of gravity, wind action, and so on as soon as it settles to the ground, one would expect the measurements to record slightly greater amounts of snowfall during the periods of more frequent measurements. Furthermore, the data may not be comparable because of the personal bias of the various observers in their selection of the points at which to make the snowfall measurements. The amount and sign of this error, of course, vary from observer to observer. Examination of snowfall data which is currently being gathered demonstrates only that the error can be considerable and may well lead to faulty conclusions about trends in snowfall. For this reason it is not proposed to subject these snowfall data to any searching statistical analysis here.

To illustrate the temperature trends in various parts of Canada since official temperatures were first observed, Figure 1 shows the graphs of the ten-year running means of the temperature for various regions. In this figure the ten-year means are plotted on the final year of the decade. Along the coast of British Columbia, there have been fluctuations of the order of 2° F. In Alberta, the decade of the 1880's was cold and the warming trend thereafter reached a maximum in the late 1940's. Colder temperatures have prevailed in the last few years. In Manitoba and northwest Ontario, the temperatures in recent years have followed much the same pattern, but there was evidently a more spectacular rise after the cold period around 1880. In central Ontario there was a rapid rise in temperatures during the latter part of the nineteenth century. This was followed by a period of fairly uniform temperatures which lasted until recent years when temperatures have been higher. The temperatures in Nova Scotia and Prince Edward Island follow the same general pattern except that there was a secondary cold period ending in 1926 in the middle of the record. It should be noted that the range

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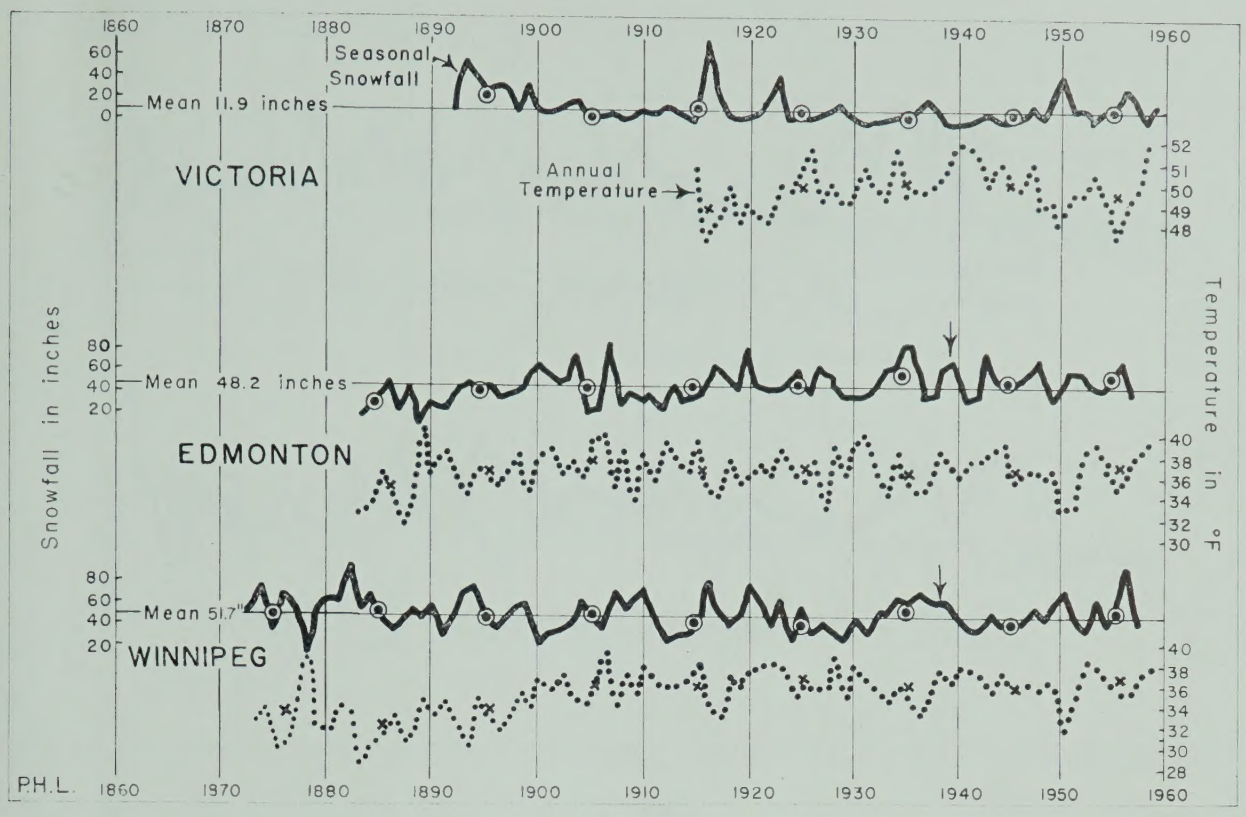

FIG. 2.

of fluctuations of the ten-year mean temperature in all these regions has been of the order of 2° to 3°F. compared to the one increase of 1°F. attributed to the city effect.

Figure 2 illustrates the first of three figures on which the seasonal snowfall (indicated by the solid line) has been plotted. The mean snowfall for each decade is indicated by a dot enclosed by a circle; the reference line represents the mean seasonal snowfall for the complete period of record. The annual temperatures, instead of being ten-year running means as shown in Figure 1, are joined by the dotted line. The average temperatures for the decade are indicated by a cross. The major relocation of meteorological observation stations brought about by the advent of aviation made it impossible to find eight records where the site had remained unchanged throughout the period of record. An arrow has been used on the graph to indicate where an observing site has moved from a city to a nearby airport.

In the case of Victoria, the observations were taken at Esquimalt prior to 1915, and since that time they have been taken at Gonzales Observatory. During the period for which the temperatures at the Gonzales site were plotted, the two decades with the coldest temperatures were also decades with above normal snowfall. Not only were the last ten years in Victoria cold, but the snowfall was greater than in any decade since 1900. In eight of the past ten winters the snowfall was above the long-term mean. Such evidence suggests that there is no likelihood of finding a decrease in snowfall at Victoria. It also illustrates that the heaviest snowfall in Victoria occurs with colder temperatures.

At Edmonton the observations were taken at a site in the city during the early years, and at the airport since 1938. During the interval from 1910 to the late 1940's, when there was above normal temperature, the snowfall remained at or above the long-term mean. With lower temperatures in recent years it has still remained high. In the earlier years at Edmonton, the coldest period on record, there was also the least snowfall. In the cold winter climates in the central area of the continent there has not been the same decrease in snowfall accompanying rising temperatures as has occurred at Victoria. The variation in the snowfall at Calgary has been similar

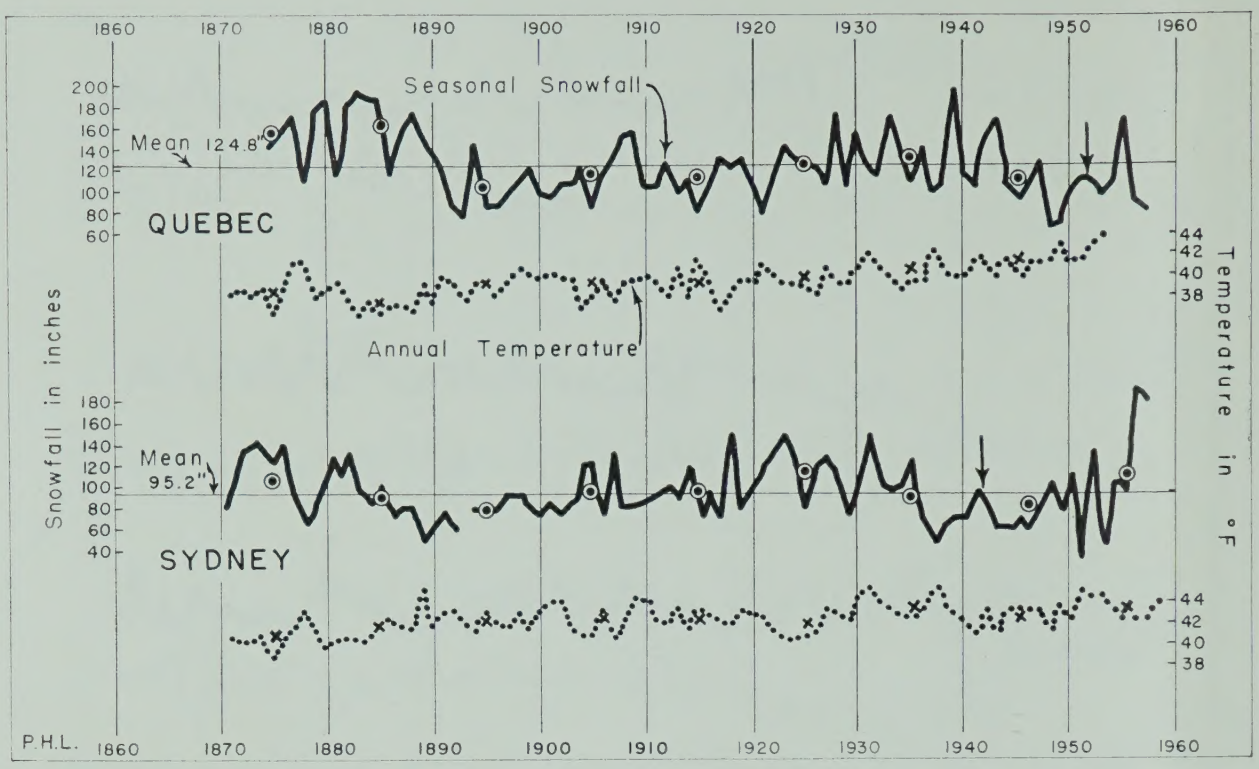

FIG. 3.

to that at Edmonton. It would seem that this is one section in Canada where the snowfall is apparently increasing.

The temperature rose sharply for a forty-year period after 1880 in southern Manitoba. At Winnipeg there appears to be a very slight downward trend in the snowfall during this period. As the temperature has levelled off during later years, snowfall has slightly increased. When snowfall records for all parts of Canada are examined, it is evident that the snowfall at Winnipeg has been the most uniform throughout the period of record, and has had the least variation from winter to winter.

At Sydney, as is apparent on Figure 3, one characteristic of the seasonal snowfall, in contrast with that of the prairie provinces, is the wider seasonal variations. Here, both the minimum and maximum snowfall on a record that began in 1871 have occurred since 1950. The two decades with the greatest snowfall were in the 1950's, when the temperature was the warmest, and in the 1870's, when the temperature was coldest. Following the 1870 decade with its increasing temperature, snowfall was at or below the long-term average until the decade beginning in 1920, when heavy snowfall again occurred with a slight recession in the temperature. Since that period the inverse relation of temperature and snowfall has not held. Snowfall seems to be more cyclic and more dependent on some control other than temperature. There is slight evidence of a long-term trend.

At Quebec, the observations were taken at the observatory on the Plains of Abraham until 1953, and then at the airport. There was a very heavy snowfall in the cold period prior to 1890, but since then, with the temperature apparently slowly rising, there has been no noticeable decrease in snowfall.

Data for Toronto and Montreal are given in Figure 4. The observing site in Toronto is at the headquarters of the Meteorological Branch at 315 Bloor Street West, and in Montreal at McGill University. It is immediately evident that they both exhibit characteristics not found in the data examined up to this point. In the cold period at Toronto around 1870, the seasonal snowfall was quite variable, but

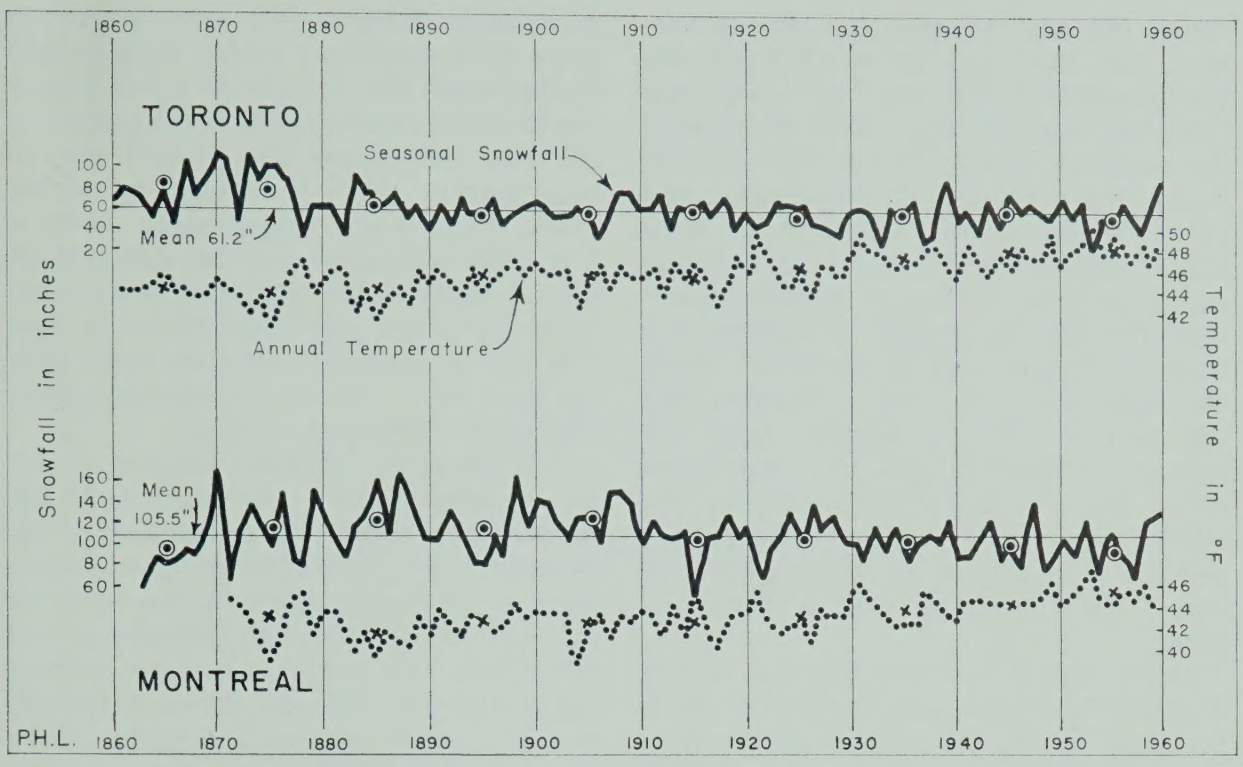

FIG. 4.

since then it has been remarkably uniform, apart from some wider fluctuations, mainly during winters with very light snowfalls, in the 1930's and in the last decade. Since 1880 there have only been three winters when the seasonal snowfall exceeded 80 inches, whereas this happened five times in the ten previous winters. At Montreal there has been a noticeable decrease in the occurrence of extremely snowy winters. Snowfalls of greater than 140 inches occurred quite frequently prior to 1910, but there have been no similar occurrences since that time.

The most striking feature of these graphs is the evidence of a definite trend to lower snowfall persisting over most of the period of record. At Toronto the greatest decrease in snowfall occurred just around 1880, with a slower rate of decrease in evidence throughout the remainder of the record. At Montreal the sequence of occurrences has been slightly different. Snowfalls in the decades beginning in 1880 and 1900 were the greatest on record there, but since 1910 there has been a remarkable downward trend in amount.

When trend lines are fitted to the data for Toronto it is found that the snowfall is decreasing at the rate of 22 inches per century when the complete record is used. As has been mentioned, it is evident that a great deal of this decrease occurred during the period around 1880. If a trend line using only data for the eighty years since 1880 is used, the rate of decrease is lowered to only 6.3 inches per century. For the complete period of record at Montreal, the trend in snowfall is decreasing at the rate of 14 inches per century. However, as has been stated previously, most of this decrease has occurred in the period since 1910. When a trend line is based on only the last fifty years of the record, it is found that snowfall during that period has been decreasing at a rate of 28 inches per century.

In conclusion, from the data presented it is clear that at Edmonton and Winnipeg the seasonal snowfall trend is steady or increasing slightly. This increase, however, may be due to the greater frequency of observations, as was pointed out above. In the maritime climate of the West Coast, where the temperature is more critical in determining whether or not precipitation falls in the form of rain or snow, the snowfall has varied inversely as the temperature, and has reflected temperature cycles. These temperature cycles are great enough to

cancel out any influence the city of Victoria may have had on snowfall. On the East Coast at Sydney, and also at Quebec City, the snowfall has varied throughout the period of record. Part of this variation is due to the changes in temperature, and part is likely due to changes in the total winter precipitation caused by varying storm patterns. The only definite downward trend in the amount of snowfall has been at Toronto and at Montreal. These two cities are particularly favourable sites for such a trend to develop. Both the general warming trend in temperature which has persisted fairly uniformly for almost eighty years throughout the region, and the rapid growth of the metropolitan areas, would facilitate such a downward trend.

If this trend is carried into the future, it should be determined how much of it has been due to the general rise in temperature, and how much to the warming caused by the growth of these two metropolitan areas. In a paper titled "Is Our Snowfall Decreasing?" and delivered at the 1958 Annual Meeting of the Eastern Snow Conference, Richard Ashely[5] discussed the long-term trend of the snowfall at the Blue Hill Meteorological Observatory at Milton, Mass. (This site has remained relatively unchanged over the period of record and has not been surrounded by metropolitan development.) At the Blue Hill Observatory the last thirty-six seasons averaged 2.5 inches less snow than the first thirty-six seasons on record. During the same periods the decrease in the snowfall at Toronto has been 4.4 inches. Thus, in comparing the Toronto and the Blue Hill trends, it could be concluded that the general warming trend in the Toronto region and the warming due to the city itself have been about equally efficient in inducing the decreased snowfall. While the city effect is permanent, the general temperature trend is not, and a reversal in the general temperature trend would again increase the snowfall, but to only approximately 2 inches less than it would have been without the city.

In attempting to extend the snowfall trend in Montreal into the future, there is more difficulty. The rate of decrease in snowfall in the past fifty years seems too large to be explained simply by increased temperatures. In my opinion it has been a combination of a warming trend caused by the city reinforcing the general rise in temperatures, plus a change in winter storm patterns and precipitation. Since it is possible only to forecast that one of these three conditions, the city effect, will remain relatively unchanged in the future, it does not seem reasonable to use the trend over the past fifty winters to forecast future changes in Montreal snowfall.

The headline "It can't happen again" was mentioned in the introduction. As has been argued above, the probability of extremely heavy snowfalls in metropolitan areas is decreasing. Even so, the writer of the caption had the same difficulty as any other forecaster issuing a forecast. During the winter of 1959 his forecast for the non-occurrence of an extremely heavy snowfall in a single day proved accurate, but the *total snowfall* for the past winter was greater than for any winter since 1882.

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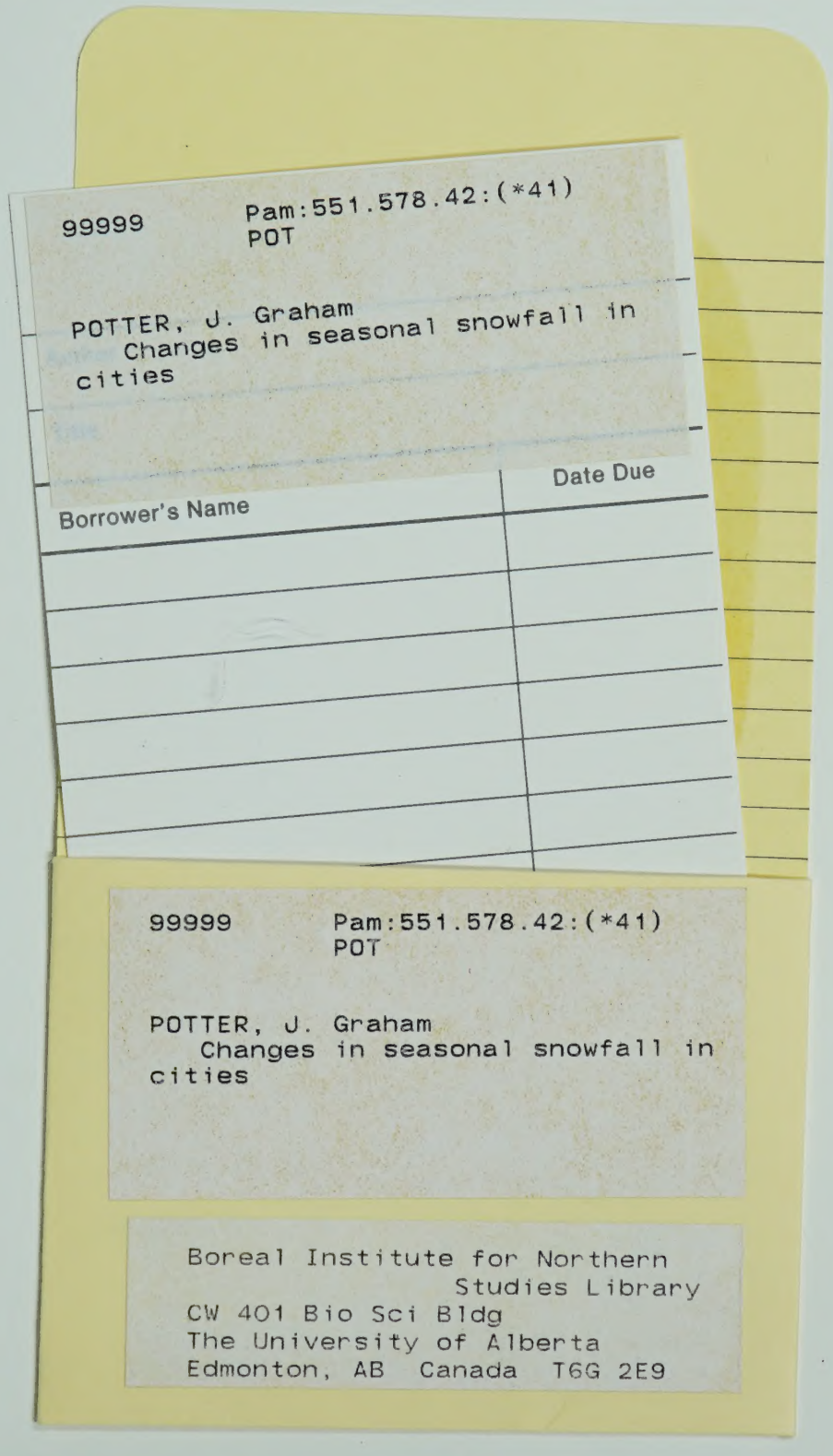
RÉSUMÉ

L'expansion urbaine modifie le climat en favorisant l'accroissement des températures et des précipitations atmosphériques moyennes. Cet article présente une étude des effets du développement urbain sur les précipitations neigeuses par l'examen des données statistiques de plusieurs années pour quelques villes canadiennes. On peut observer une diminution des chutes de neige à Toronto et à Montréal seulement. L'auteur explique ce phénomène en l'attribuant (1) à un changement général du climat et (2) à l'expansion urbaine.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